PROPULSION DIRECTORATE

Monthly Accomplishment Report
September 2005

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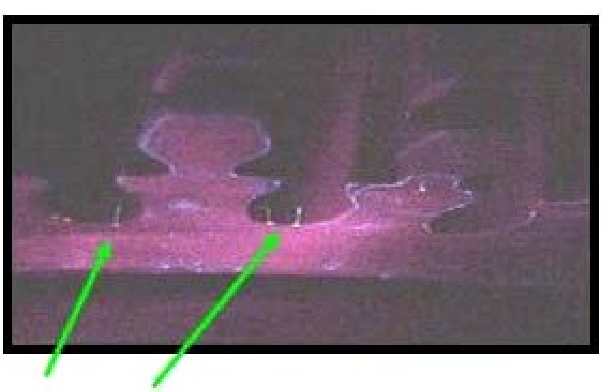
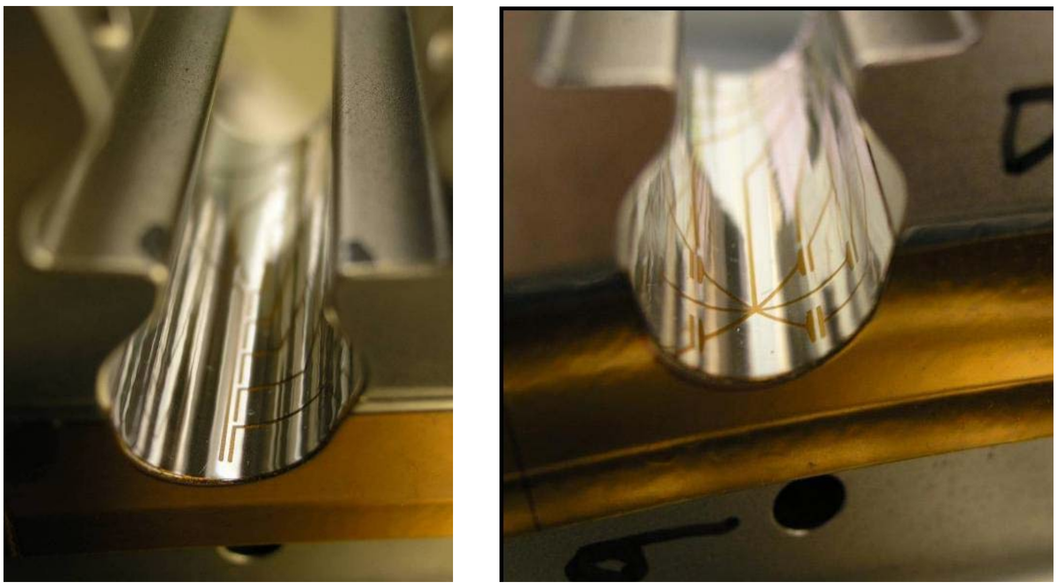
SCRAMJET DEMONSTRATOR GETS X-PLANE DESIGNATION: In a letter dated 27 September 2005, the US Air Force (HQ USAF/XPPE) officially granted the Propulsion Directorate's scramjet flight test vehicle the designation X-51A. Since the introduction of the legendary X-1 in 1946, the X-plane designations have identified experimental aircraft and rockets used to explore new aerospace technologies. The Propulsion Directorate is currently working with Pratt & Whitney (P&W)/Rocketdyne's Space Propulsion Division and Boeing's Transformational Space Systems Division to design the X-51A scramjet powered flight vehicle to explore the airbreathing system-level potential of scramjets. This program, dubbed the Scramjet Engine Demonstrator - WaveRider (SED-WR) Program, will execute multiple flight tests of the SED-WR vehicle beginning in FY 2009. Each flight vehicle will consist of one P&W scramjet engine, based on technology developed under AFRL/PR's Hydrocarbon Scramjet Engine Technology (HySET) Program, integrated by Boeing into an expendable WaveRider configured air vehicle. During the flight demonstrations, an SED-WR vehicle will be carried aloft by a B-52 aircraft to an altitude of about 35,000 feet and released. Initially propelled by an Army ATACMS solid rocket booster, the scramjet will takeover at approximately Mach 4.5 and the vehicle will accelerate to a flight speed between Mach 6.0 to 7.0+. Applications for this propulsion concept include access-to-space and fast-reaction military systems. (Mr. C. Brink, AFRL/PRAT, (937) 255-7611)

Artist's rendering of the SED-WaveRider flight test vehicle

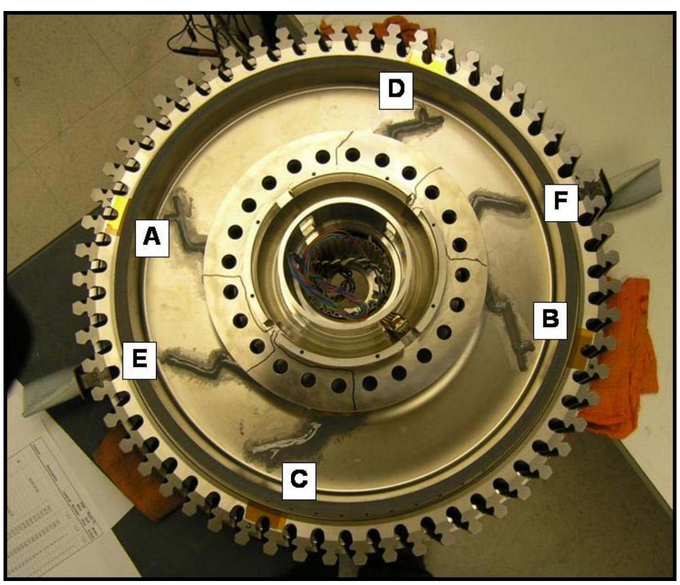
F119 HIGH PRESSURE TURBINE HEAT TRANSFER SENSORS DEVELOPED IN-HOUSE: Researchers in the Propulsion Directorate's Heat Flux Instrumentation Laboratory have developed sensor technology to investigate thermal-structural interactions in the F119 engine. Specifically, thermal stress fractures identified in F119 broach slots could significantly reduce the life of the F119 High Pressure Turbine (HPT) disk. Engineering models do not accurately predict heat transfer in this region, so AFRL/PR's Turbine Research Facility is preparing a unique test to investigate the problem using newly-developed high density heat flux gauge arrays. Multiple thin film sensors were designed and produced in-house and then mounted onto an actual F119 HPT rotor. The sensors are located within the small cavity



Fracture indications in the broach slot at the forward edge that feeds cooling flow to the base of the rotor blades. It is a challenging measurement, and represents the first attempt to capture multipoint, non-intrusive surface heat flux measurements inside the broach slot of a real, fully-rotating, cooled turbine. Four slot locations have been instrumented on the disk with different sensor patterns to map surface heat flux. Lead wires are carefully routed through the disk to the hub, where they connect to a 300 contact slip-ring. The rotor has been assembled and installed, and the new rotor sensors were tested successfully prior to running the blowdown test. The ultimate goal of this Agile Combat Support is to improve understanding of heat transfer in the slot to allow better design optimization, improve accuracy of Low Cycle Fatigue (LCF) and fracture life predictions, and allow extension of HPT disk life to 8650 TACs (i.e., Total Accumulated Cycles). (Dr. R. Anthony, AFRL/PRTT, (937) 255-6768)



Small sheets of platinum thin film sensors lie flush with the broach slot surface to obtain non-intrusive surface heat flux measurements on the cooled F119 rotor disk



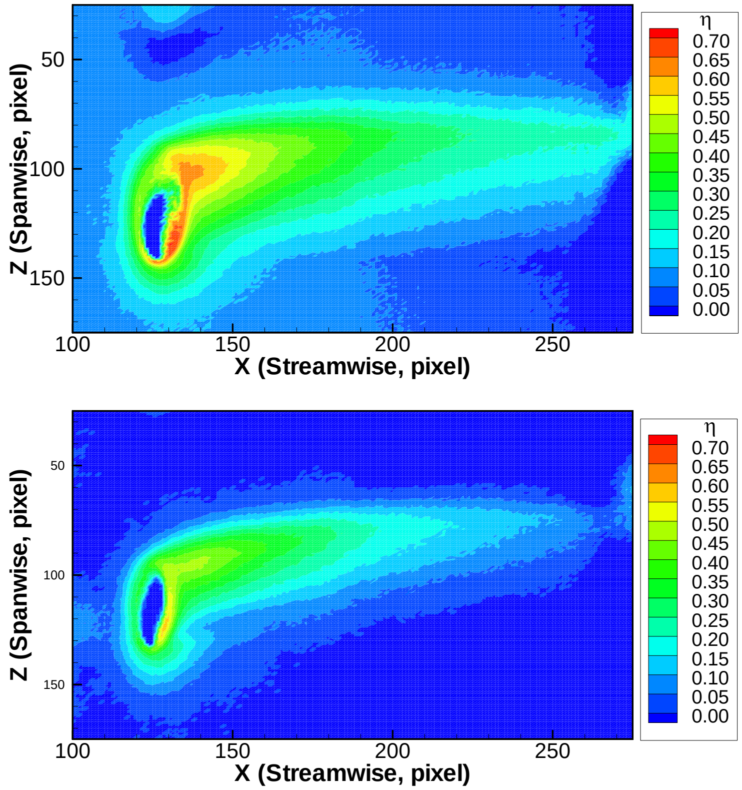
F119 HPT disk instrumented with 4 broach slots and 2 blade platforms

PATENT OFFERS NEW METHOD FOR FABRICATING MICROSYSTEMS: On 13 September 2005, Drs. Phil Wapner and Wes Hoffman of the Propulsion Directorate's High Temperature Components Group were granted US Patent No. 6,942,747. This patent, titled "Microtubes with Axially Variable Geometries and Method of Manufacturing Same," describes techniques for manufacturing microscopic tubes with any axial distribution of cross-sectional shape. It has application to the manufacture of miniature devices, particularly micro-electromechanical systems (MEMS) and the closely related fields of micro-fluidics and micro-optical systems. Presently, these technologies involve micro-machining on a silicon chip to produce a variety of devices (e.g., sensors, detectors, gears, engines, actuators, valves, pumps, motors, mirrors, etc.) on the micron scale. Such microsystems are made almost exclusively on planar surfaces using technology developed to fabricate integrated circuits, that is, the fabrication of these devices takes place on a wafer and the device is formed layer-by-layer with standard clean-room techniques that include e-beam or photolithography, thin-film deposition, and wet or dry etching. The subject patent takes a different approach to the manufacture of these miniature devices that overcomes some of the disadvantages associated with conventional planar techniques. (Dr. W. Hoffman, AFRL/PRSM, (661) 275-5768)

Dr. Phil Wapner

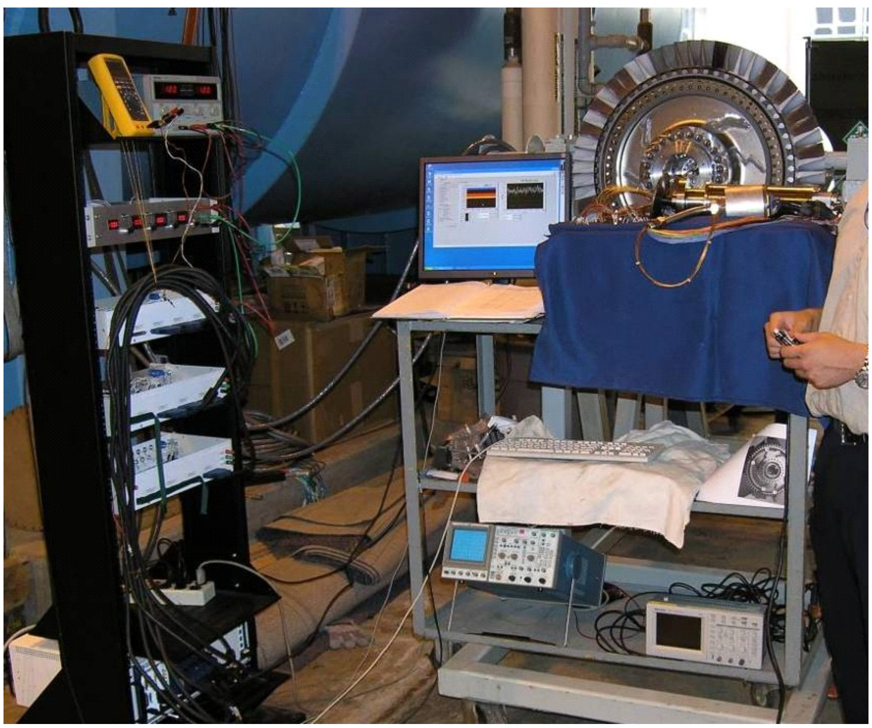
Dr. Wes Hoffman

SHAPED-HOLE/PULSED COOLANT FLOW STUDIED: Propulsion Directorate researchers have completed an experimental investigation of leading edge film cooling for turbine airfoils. This experimental study was performed in AFRL/PR's Aerothermal Heat Transfer Laboratory at Wright-Patterson AFB, Ohio. Instead of the continuous film cooling flow and the classic cylindrical hole geometry currently used in turbine engines, this research employed pulsed film cooling flow and diffusion shaped-hole geometry. An infrared thermography technique was used to obtain both the heat transfer coefficient (h) and film effectiveness (η) from a single transient test. The coolant pulsation was controlled by the opening and closing times of two synchronized pulsed valves, which created a combination of pulsing frequency (PF) and duty cycle (DC). Three duty cycles of 50%, 75%, and 100% (continuous coolant) and two pulsing frequencies of 5 Hertz (Hz) and 10 Hertz were investigated. The duty cycle (%) is defined as the valve opening time with respect to the total time in an opening-closing cycle. In the study, hot mainstream air and cooler coolant (also air) injected through a single shaped hole or a cylindrical hole were imposed suddenly on an ambient temperature test surface. The surface temperature response was captured using an infrared imaging system. The measured surface temperature along with the mainstream and coolant temperature histories were used to determine the heat transfer coefficient and film effectiveness at every point of the imaging field (320 x 240 pixels). The goal of film cooling is to obtain higher film effectiveness (to better protect the turbine blade/vane) and lower heat transfer coefficient (to prevent the hot gas stream from transferring heat to the turbine blade/vane). By combining the effects of both heat transfer coefficient and film effectiveness, the film cooling performance was evaluated. The results show that the pulsed cases provide better cooling performance than the continuous coolant on the majority of locations on the test surface for the shaped hole geometry with the exception of very small region within the film hole span location. The performance superiority of the pulsed coolant over the unpulsed (continuous) coolant occurs not only for the shaped hole but also for the cylindrical hole. The results also show that the shaped-hole cases are superior to those of the classic cylindrical hole in film cooling performance no matter whether the coolant is pulsed or not. The research efforts clearly demonstrate that film cooling flow can be significantly reduced by substituting the pulsed coolant for continuous coolant to obtain the benefits of higher effectiveness and lower heat transfer coefficients. The reduction of film cooling flow ranges from 18% to 41% for this research depending on the duty cycle and pulsing frequency studied. These important findings will contribute to future performance improvements for turbines. A



Distribution of local film effectiveness showing the superiority of shaped hole coolant (top) over the conventional cylindrical hole geometry (bottom) technical paper* has been submitted for presentation at ASME Turbo Expo 2006. (Dr. S. Ou, AFRL/PRTT, (937) 255-6043)

HIGH-SPEED ROTOR INSTRUMENTATION SYSTEM DEVELOPED: The Propulsion Directorate has built and tested an instrumentation system for use with their new high density heat flux gauges. The complete system was connected to an F119 turbine rotor and successfully tested prior to performing rotating tests in the Turbine Research Facility (TRF). These system tests were performed by applying convective heat flux to the rotor's broach slots and blade platforms before placing the rotor onto the test stand. The instrumentation responded well to surface heat flux with excellent signal-to-noise ratio, and the signal processing functioned smoothly. The signal processing hardware and software for the rotor system were developed in-house over the past several months. The system consists of high-density platinum thin film arrays designed and manufactured in PR's Heat Flux Instrumentation Laboratory, 32 channels of custom made differential high frequency pre-amplifiers with anti-aliasing filters, a constant current source with 4 separate channels with display, a high speed data acquisition system capable of sampling at 800 kS/s on 32 channels simultaneously, and streamlined data acquisition and data processing code written in Matlab®. The user-written Matlab® code allows the user to set-up the data system, acquire data off a TRF trigger, inspect the data signals, reduce the signal to film temperatures, calculate heat flux, and plot and analyze results. The code is fast, efficient, and allows all data reduction to be performed quickly on a single machine running one application. The electronics were first tested and debugged in AFRL/PR's Room 21 Wind Tunnel. The Matlab® code was first implemented in AFRL/PR's Turbine Engine Fatigue Facility (TEFF) and subsequently improved for the TRF set-up. (Dr. R. Anthony, AFRL/PRTT, (937) 255-6768)



Instrumentation system for use with new high density heat flux gauges

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* Ou, Shichuan and River, Richard B., "Shaped-Hole Film Cooling with Pulsed Secondary Flow," GT2006-90272.